BIOMECHANICAL ANALYSIS OF FULL-ARCH IMPLANT-SUPPORTED REHABILITATIONS WITH DIFFERENT DESIGNS

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ABSTRACT

The aim of this research was to perform a biomechanical analysis of different designs of a full-arch screw-retained implant-support rehabilitation, mainly in two components of the prosthetic structure: abutments and prosthetic screws. 3D simplified models of a mandibular arch with seven variations of an implant-supported rehabilitations were developed, modifying the implant’s number (4 or 6) and axis (straight and tilted) and the framework cantilever size. Results obtained show that longer cantilevers supported by tilted implants should be avoided in order to prevent mechanical and biological complications.

Keywords: biomechanics, dental implants, dental prosthesis, abutments, prosthetic screws.

INTRODUCTION

Full-arch implant-supported prosthesis is a treatment solution to rehabilitate an edentulous patient that mostly resembles the natural dentition, due to the fact that the prosthetic teeth are fixed in the edentulous jaw through dental implants. In this way, this option contributes to an improvement of the masticatory efficiency, confidence and patient’s self-esteem.

Clinical success of this treatment option depends not only on the survival and success rates of the dental implants inserted (usually between 4 and 6 depending on local factors involved, mainly anatomical and physiological) but also on biological and mechanical complications of the rehabilitation (implants and prosthesis) while in function.

Mechanical complications directly affect the prosthetic structure and can be avoided or minimized by an exhaustive planning and by ensuring that the rehabilitation is correctly executed. Such complications may include, e.g.: fracture or loosening of prosthetic screws or abutments; ceramic chipping or fracture of the veneering material; framework fracture; loss of filling material in access holes; fracture of the opposing restoration [1].

This biomechanics can be studied in vitro, by using numerical models and the finite elements method (FEM), widely used in dental medicine research in the last two decades [1-3]

The main objective of this research was to do a biomechanical analysis of these rehabilitations in terms of stress distribution, depending on the implant’s number and insertion axis, and also the dimension of the cantilevered implant-supported prosthesis. Focus was directed to the abutments and screws that support and retain the prosthetic framework.
MATERIAL AND METHODS

Three different phases were defined in this research:

1. 3D design of all rehabilitation components;
2. FEM for each model (Table I);
3. Load simulation with different angulation and application sites.

Accordingly to the established goals, seven models were designed: I - 6 straight and parallel implants and a prosthetic structure without cantilevers; II - 4 straight and parallel implants; III - 4 implants, 2 anterior straight implants and 2 distal and tilted 30º to the occlusal plan. Model 2 and 3 had three variations according to the cantilever size of the prosthetic structure: 0, 7 and 10mm.

Table I - Characterization of the models in nodes and elements. Model 1 example.

<table>
<thead>
<tr>
<th>Model</th>
<th>Nodes</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model I</td>
<td>1500454</td>
<td>971976</td>
</tr>
<tr>
<td>Model II(1)</td>
<td>1378283</td>
<td>914413</td>
</tr>
<tr>
<td>Model II(2)</td>
<td>1352485</td>
<td>889064</td>
</tr>
<tr>
<td>Model II(3)</td>
<td>1390880</td>
<td>922519</td>
</tr>
<tr>
<td>Model III(1)</td>
<td>1376013</td>
<td>913300</td>
</tr>
<tr>
<td>Model III(2)</td>
<td>1385917</td>
<td>919907</td>
</tr>
<tr>
<td>Model III(3)</td>
<td>1389853</td>
<td>922463</td>
</tr>
</tbody>
</table>

All the models included a simplified mandibular arch (model I with cortical and trabecular bone), 4 or 6 implants with respective abutments and prosthetic screws and a simplified prosthetic metal structure with variation in cantilever dimensions. Regarding boundary conditions, implant osseointegration were assumed to be 100% with rigid connections between implant-abutment, abutment-screw and abutment-structure. In the mandibular arch, the boundary conditions were set rigid on the inferior surface of the arch.

Implants, abutments and screws were designed in 3D according to NobelBiocare specifications: Speedy Groovy implants (Ref. 32150 NobelBiocare) with external connection, 4.1mm diameter and 13mm length; straight abutments with a height of 4mm (Ref. 29182 NobelBiocare); 30º angulated abutments (Ref. 29192 NobelBiocare) and prosthetic screws M1,4x2 (Ref. 29285 NobelBiocare).

The mechanical properties of all components are resumed in Table 2 [4].

Table 2 - Mechanical properties of modelled materials [4]

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (Kg/m³)</th>
<th>Young Modulus (GPa)</th>
<th>Poisson’s Ratio</th>
<th>Elastic Limit (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical Bone</td>
<td>1500</td>
<td>15</td>
<td>0,30</td>
<td>---</td>
</tr>
<tr>
<td>Trabecular Bone</td>
<td>1500</td>
<td>1,5</td>
<td>0,30</td>
<td>---</td>
</tr>
<tr>
<td>Pure Titanium, IV grade (Implant)</td>
<td>4510</td>
<td>105</td>
<td>0,34</td>
<td>480-655</td>
</tr>
<tr>
<td>Pure Titanium, II grade (Abutment)</td>
<td>4510</td>
<td>103</td>
<td>0,34</td>
<td>275-450</td>
</tr>
<tr>
<td>Titanium alloy Ti6Al4V (Structure and screws)</td>
<td>4430</td>
<td>114</td>
<td>0,34</td>
<td>800-1100</td>
</tr>
</tbody>
</table>

-1476-
A mechanical static analysis of the abutments and prosthetic screws was made (AnsysV15®) with vertical and oblique (30°) loads of 10N, applied in different locations to simulate different occlusion schemes: anterior to the cantilever (Test I), unilateral on the cantilever (Test II), bilateral (Test III), anterior (Test IV) and posterior (Test V). After a preliminary analysis, loads compatible with chewing activity were selected to present a quantitative biomechanical analysis.

RESULTS

The results of stress and strain distributions on different models and different simulated loads are expressed in a colour gradient, ranging from red to blue, where red represents the highest stress values. The models registering the lowest and highest stress values observed in each test, under vertical or oblique loads, are presented in Figures 1, 2, 3, 4 and 5. The results of maximum stress and strain on different models and tests conditions are resumed in Table III, considering the worst situations in each test.

Fig. 1 - Results of Test I, in models II (2) and III (2).
Fig. 2 - Results of Test II, in models II (2) and III (3).
Fig. 3 - Results of Test III, in models I and III (2).
Fig. 4 - Results of Test IV, in models I and III (3).
DISCUSSIONS AND CONCLUSIONS

In our research, the highest stress values were observed in abutments, in test II (load on cantilever), model III (3) under oblique loading. The greatest maximum strain was observed in the same situation. These results were expected and in accordance with other authors [5-6], since this model used an extended cantilever of 10mm over an angulated distal abutment. The model with the least amount of stress in abutments was model I with distributed vertical load. The same model also produced the minimum level of strain but with load on posterior sectors. In both cases, since the load was distributed between 6 implants, minimal stress and strain were expected in each abutment [7]. In the four implant models, the areas where stress and strain were most commonly concentrated were in the implant-abutment interface, the distal area in vertical load, and the lingual area in oblique load. The screw-abutment interface was also often found to be an area of stress and strain concentration in models without cantilever under vertical load. Similar results were found in experiments performed on All-on-4 rehabilitations by Silva et al [7] and Bevilacqua et al [8], who also report equal stress concentration interfaces.

Prosthetic screws were identified in many tests as areas of less concentrated stress and strain [9].

Regarding cantilever extension, a direct correlation between stress concentration and cantilever size was only observed in the case of vertical load, load applied on the cantilever, (type III models III only) and load on posterior areas with increases of 51.0%, 37.8% and 43.7%, respectively. The same correlation was observed when comparing models II and III with 7 and 10mm cantilevers. The highest increase of 93.2% was observed in vertical distributed loads, in the model with 4 straight implants. Other authors, like Varinauskas et al [6] and Sertgoz and Guvener [5], reported similar results. In a similar study, Varinauskas et al
[6] concluded that longer cantilevers caused greater stresses on the screws and prosthetic components.

Bevilacqua et al [8] analysed stress in the prosthetic framework, implants and bone using different implant angulations. The authors detected highest stress concentrations in the interfaces between distal implants and the prosthetic framework while loading the cantilever. Sertgoz and Guvener [5] also report rising stress levels as a consequence of increased cantilever length, in a 6 implant-supported prosthesis.

When it comes to comparing angulated and straight abutments, in almost every test there was an increase of stress and strain when using angulated abutments in distal implants (except in test IV with oblique forces). The highest increase observed was of 43.6% in test II with vertical loads.

In order to simulate normal and maximum occlusal forces, the loads of 10N were multiplied, obtaining values of 50, 100, 200, 300, 400 and 500N. In tests I and II, the resulting maximum stress values in abutments were above the elastic limit of titanium in all models. This fact could significantly increase material failure, leading to plastic deformation.

From this stress analysis, interface stability between components in implant rehabilitation is a key factor in successful treatment. In addition, non-axial contacts should be avoided, since they put more stresses on prosthetic components.

The present study, due to its biomechanical nature, involves some limitations and simplifications. Biological structures exhibit complex geometries. Accordingly, simplified models are usually developed so as to perform a preliminary biomechanical analysis with the finite element method prior to experimental analysis. These same simplifications occur in most studies employing finite element analysis of implant-supported rehabilitations [6-11].

Within the limitations of the study we can conclude that the results obtained suggest that the clinical situation with lowest stress values was the prosthesis supported by 6 implants under vertical loads, without cantilever and only with straight abutments. The highest stress values found were located in the abutments adjacent to a cantilever, supporting an oblique load, on a model with 4 implants, angulated distal abutments and a 10mm cantilever. In the 4 implants models, highest stresses and strains were located in the implant-abutment interface. The prosthetic screws were, in many testes, areas of minimum stress and strain.

REFERENCES


